The Role of Digital Image Processing in Telecommunications

Dr. Najmi G. Haider
SZABIST
Karachi, Pakistan

Abstract:

Image processing involves the use of techniques developed for manipulating images with the objective of enhancing some aspect of interest in the image. The type of image depends on the sensor used to capture the image, ie. camera, spectral, radar, sonar, thermal. This paper considers the role of image processing in applications in telecommunications involving the acquisition and transmission of images from large distances. These images are processed using algorithms developed on computers to enable the interpretation of the data. Such applications include images of distant planets transmitted by space probes, remote sensing applications of which there are several specialized areas such as monitoring and exploration of the earth's natural resources (eg. vegetation, oceanography, mineral exploration, atmospheric ozone layer etc.), weather forecasting, map making, military intelligence. Image processing vastly adds to the effective use of these applications.

Cellular phones now have the capability to capture and transmit images. Though it would require substantially more processing power than is present in cellular phones now, it is suggested given the developments in information technology, it should become possible to build lip reading capability and speech recognition capability in cellular phones. The cellular phone has all the hardware requirements for acquisition of both the audio and visual data. Designing lip reading capability in cell phones could make it possible for the mute persons to communicate with others via cell phone. Combined with speech recognition, this would enable voice communication to be made over low bandwidth channels. However, the present state of audio and visual speech recognition technology will need to attain significantly better performance than what is achievable today.

This paper reviews the applications of image processing, its implementation, and image processing algorithms.

1. INTRODUCTION

Digital image processing has a fundamental role in several and differing disciplines such as security, medical imaging, robotics, geological exploration, cartography, environmental change detection, military intelligence and telecommunication. With the advances in information technology, vast amounts of data are being produced as well as the capability to process the data. Much of this data is of a visual nature and hence digital image processing has attracted considerable attention as these techniques are necessarily needed if the data is to be meaningfully interpreted and used. Algorithms have been developed to process the raw data received from the source so that aspects of interest stand out in the image, correction for distortion (geometric due to effect of rotation of the earth, and radiometric variations from changes in radiance, both atmospheric and instrumentation related), and enhancement such as contrast, and sharpening of blurred areas to improve image quality. The resulting images can then be studied for visualization and interpretation by experts.

With the launching of space probes to the moon in the late 1950's, images being received back at earth had distortion problems related to the camera and associated electronics being used on the space craft. The images were blurred, lacked focus and noisy. Image processing techniques were developed to improve the image quality [1]. In fact, so critical was the role of image processing that NASA established in 1965 the Image Processing Laboratory as a division of its Jet Propulsion Laboratory. In 1984, the Multimission Image Processing Laboratory was formed.

Initially, analog techniques were being used in the space probes for the transmission of images, and analog methods applied for improving the image quality, which are difficult to work with. Owing to the versatility of digital methods for manipulating images, the received analog video images were digitized and then signal processing techniques applied to it. Missions to more distant planets required that signals from the space probes be transmitted back to earth in digital form, since over the large distances the analog signal would become too weak to be differentiable from the background noise of space. Therefore the digitization was performed on the spacecraft itself, and the data transmitted as a digital signal.

The techniques pioneered for digital processing of images from space probes served as a basis for application in other applications of remote sensing, and areas such as biomedical imaging etc.

2. REMOTE SENSING APPLICATIONS

Remote sensing is a specialized application of several technologies with the purpose of observing objects from a distance [2]. These objects of interest may be earth related or objects such as the planets in outer space. The cameras and imaging instruments that collect the remote data could be airborne or spaceborne. Airborne methods are more expensive and cover smaller areas. Spacecrafts such as the space shuttle and satellites are able to collect data from greater distances (heights) and hence cover significantly

larger areas, the image resolution being determined by the instruments capability. Satellites are either geostationary i.e. they remain at the same point over the Earth surface, or polar orbiting i.e. they orbit longitudinally from pole to pole. As the earth is also rotating about its axis, each orbit passes over a longitudinal area to the west of the previous orbit, and in this manner can cover the entire surface of the earth. Remote sensing has developed into a very specialized discipline having varied applications. Some applications of remote sensing are:

Vegetation: The absorption and reflectance characteristics of different types of vegetation and the spectral variations they produce is used to detect, identify, monitor and assess changes in forests, grasslands, agricultural land and even the vegetation in water.

Urban and land use: Natural and man made features can be identified from the reflectance characteristics of buildings, streets, airports etc. and used for making maps and to obtain data on how the land is being used. Comparison with earlier images reveals information on urban development and population growth.

Geologic: Rock types and ages of rocks show distinct spectral variations and can be identified from their spectral signatures. It provides data on the surface distribution and types of rock formation. This applies to exposed areas. Areas covered with soil and vegetation etc. would require extrapolation by geologists based on the study from nearby areas. Its impact has been mostly to improve the process of geologic mapping.

Mineral & petroleum exploration: Mineralization has been found to occur in structural belts, shear zones, faults, fractures. Before costly field exploration can commence, target areas of high potential must be identified. A preliminary understanding of the geographic area will also be needed in planning the operations. The vast areas covered by a remote sensing platform offers obvious advantages, particularly in hostile areas such as Antarctica.

Meteorologic: One of the first use of satellites was to monitor and study the Earth's atmosphere, climatic changes and weather forecasting. Temperatures, pressure, wind speed and rate of movement of air masses can be measured, pending storms can be observed and progress tracked. Timely action can be initiated if the weather changes are deemed to take on catastrophic proportions. Ground based radar systems are also used for making weather maps.

Oceanographic: These studies include sea-surface temperature, current patterns, surface-wind action and wave motions. Phytoplankton (one celled green algae) forms the basis of the marine food chain. From changes in the colour of the ocean, the concentration of phytoplankton can be identified. All this data can be very conveniently gathered from remote sensing satellites particularly in view of the large distances to be covered in these studies.

Military: This has been the prime application of remote sensing, one that has driven developments in this field. The capabilities (spatial resolution) of these sensing systems are classified as a matter of national security, but are thought to resolve objects at about 2 to 4 meters, which is clearly superior to those used in other applications of remote sensing. Previously the preserve of governments, now there are private commercial satellite companies (IKONOS, Quickbird) that provide high resolution images, and from whom nations without their own satellite can purchase.

3. TYPES OF REMOTE SENSING

The basis for imaging in remote sensing applications is the measurement of electro-magnetic radiation that is reflected or emitted from objects being sensed. There are three types of remote sensing, grouped according to the wavelength regions the instruments are sensitive to:

i. Visible and reflective Infrared: The electromagnetic radiation from the sun (sunlight) is reflected by the objects it is incident upon. The reflected radiation peaks at 0.5 μm wavelength.

ii. Thermal Infrared: This type relies on the thermal energy radiated by objects themselves. This radiated energy for objects having normal earth temperature peaks at 10 μm wavelength. 3 μm is considered as the boundary for differentiating sensing types discussed in (i) and (ii) above.

iii. Microwave: In this category, there are two types: passive and active. Passive microwave sensing is similar to thermal infrared sensing in that it measures the microwave radiation emitted by the object. Active microwave sensing makes use of a manmade energy source such as radar to "illuminate" the object and measure the microwave energy reflected back to the sensor due to back scattering effect. The wavelength ranges from 1 mm to 30 cm.

It follows from the above that there are two types of remote sensors: passive [3] and active [4]. Passive sensors (e.g. camera) operate by detecting electromagnetic radiation from natural sources that gets reflected/ emitted by objects. In this category are optical sensors (detect the reflected sunlight, in the visible, near infrared and short-wave infrared spectral wavelengths) and infrared sensors (detects infrared radiation from warm bodies, in the middle and longwave infrared spectral regions). The reflectance is measured by spectrometers. Active sensors operate by detecting the energy reflection from objects illuminated by manmade sources like radar or laser. These sensors operate in the microwave region of the electromagnetic spectrum.

The optical sensors are also classified into categories:

panchromatic (single channel detector sensitive to radiation in a broad bandwidth range, measures the object brightness), *multispectral* (a few multichannel detectors sensing radiation in narrow wavelength bands producing a multilayer image giving brightness and colour information), *superspectral* (monitors many more spectral channels with narrower bandwidth than the multipspectral one, providing finer spectral resolution of target objects), and *hyperspectral* (also called image spectrometer since it captures images in over a 100 spectral bands producing a stack of images for the same point scanned, providing better object characterization, classification and identification).

4. DIGITAL IMAGES

An image may be in analog form such as a photograph, or it may be acquired in digital form using an electronic sensor. Analog images are digitized using d/a converter to obtain the digital representation of the image.

The digital image is a two dimensional grid of pixels (picture elements) arranged in rows and columns, each pixel value being a measure of the intensity (reflection, radiation, radar backscatter etc. depending on the type of sensor used for remote sensing) for the respective point on the scene in the image.

The amount of detail in an image is dependent on four issues:

i. Sensor spatial resolution. This determines the area size on the object that the pixel represents. It is clear that observing objects from such great distances is no mean feat. The finer the area size covered by the pixel, the clearer the image will be. If the pixel represents a larger area, the image will appear more blurred.

ii. Pixel quantization (the number of bits used to encode the pixel) and hence the intensity levels. The intensity value would be the average measurement for the area determined by the spatial resolution. The value is represented as a colour or shade of gray.

iii. Spectral resolution. This is with reference to the number of spectral bands the sensor is responsive to, eg. multispectral, superspectral and hyperspectral.

iv. Temporal resolution. The effect of this is that fast moving objects would appear blurred. If images are taken of a particular spot over time, then this is the time that the satellite would be back over that spot to scan it again.

All these resolution issues also have data size considerations, eg. doubling the spatial resolution would result in increase in data size by a factor of 4. The data also has to be transmitted back to the receiving station on earth in the case of satellites.

5. IMAGE PROCESSING ALGORITHMS

To improve the display of images image processing algorithms are designed to address specific problems such as noise, blur, geometric distortions, techniques for enhancing the image contrast to show parts clearer and even transformation to other reference domains such as frequency.

Depending on the requirement/problem with an image needing to be addressed, an algorithm appropriate to that particular problem has to be used. Using an algorithm in a situation other than that for which it was designed would present incorrect results.

Image processing algorithms work by operating on pixel values according to the processing steps defined in the algorithm and change the pixel value accordingly so that the net effect of the changes produces the improvement sought.

These algorithms may be broadly grouped as a point process, area process and geometric process.

5.1 Point Process Algorithm

The method is to scan through the image and use the pixel value at a point to calculate a new value for that point. It is used in cases where there is a need to enhance or modify pixel values.

To brighten an image requires simply adding an integer value v to the image pixel value p_i giving a new value p_n for that pixel

$$p_n = p_i + v$$

Contrast can be achieved by smoothly changing pixel values in an area of the image of *a* by *b* pixels.

$$p_n = p_i * k * e^{-(x*x/l + y*y/l))} - m$$

x and y is the pixel within the area, and k, l, m are constant values. The effect is to increasing the contrast at the centre of the image and fading it towards the edges.

Another method for improving image contrast is to use intensity histograms. By first setting an area on the image, the histogram is generated by counting the number of pixels for all possible intensity values in the area. This histogram shows the distribution of intensity values and also the range of the lowest and highest values. Applying this information to the entire image, pixel values below the histogram low value are set to 0, and those above the high value are set to the maximum value derived from the pixel quantization bit-size. The pixels with intermediate

values are multiplied per scaling with the pixel quantization range.

Highlighting a range of pixel values can be done with pseudocolouring. This method can also be used to colour a monochrome image [5].

5.2 Area Process Algorithms

These methods modify pixel values based on the values of pixels in the neighbourhood, commonly 3 x 3 pixels. It can be used to highlight some property at points in the image. Commonly used for spatial filtering such as removing repeated elements (eg. noise), sharpening, smoothing or blurring the image appearance and changing the image structure. Also, objects can be found by matching.

Spatial filtering is achieved through convolution of the image with a filter. The process computes a new value at a pixel given by the weighted sum of the pixel's original value and those of its neighbours, the weighting factor being provided by a convolution kernel made up of a n x n matrix, where n is usually 3 as mentioned above. The kernel matrix would be centered on the pixel being processed. In general, the convolution (which is actually a correlation operation) is given by

$$p(x,y) = \Sigma\, k(m,n)\, p(x+m,y+n)$$

where the image being convolved is x by y pixels, and the kernel is an m by n matrix. By setting appropriate values for the kernel, the convolution may be treated as a matched filter, the kernel representing the characteristics to be detected in the image, eg. edge detection. In terms of spatial filtering, the kernel values would determine the frequencies to be selected. Quick changes in intensity signify high spatial frequencies (eg. at edges), slow changes indicate lower spatial frequencies. A kernel that boosts high frequencies has the effect of sharpening the image, whereas a lower frequency kernel would blur the image.

Whereas convolution is a linear operation, nonlinear methods give better results. The Sobel filter is widely used for edge detection in image processing applications. The median filter is useful in removing spot noise.

5.3 Geometric Process Algorithms

This group of operations are used for correction of image distortions resulting from camera optics, to enlarge an area of interest on the image, to rotate, stretch or warp the image. This involves pixel mapping to a new location on the pixel image map.

6. REAL-TIME IMAGE PROCESSING

Digital image processing algorithms are calculation intensive requiring a considerable number of multiply and add operations. To achieve real-time image processing, these algorithms can be efficiently implemented in hardware with VLSI parallel architectures. Devices are available that can perform real time image processing of the video signal [6].

7. LIP READING IN CELLULAR PHONES

Present cellular phones models now also have a camera providing the capability to transmit both voice and pictures. With an appropriately positioned camera near the mouthpiece of the cell phone focused on the speakers mouth and lips, it should be possible to capture clear images of the lip and mouth movement [7,8]. Given sufficient computing power within the cell phone to perform lip reading, and combining it with text-to-speech at the receiving phone, this would provide mute persons with the ability to use cell phones (or telephones) to communicate with others. However, a high degree of accuracy would be required from the lip reading software to make the application practically useable.

8. CONCLUSION

Image processing has a fundamental role in applications requiring the capture and transmission of images, without which their effectiveness would be severely impaired. Although initially analog images were used, these were replaced by digital imaging owing to flexibility of applying digital processing techniques to the transmitted images. However after processing, the images still require information from other sources (for verification) and trained experts for correct interpretation of the results.

Image processing algorithms address specific problems associated with images captured at a distance, such as correction for distortion and image enhancement. The large number of computations involved necessitate simpler algorithms be developed, and to perform the processing through dedicated VLSI hardware in parallel. This is all the more necessary since more sophisticated sensors are being developed, which would produce vast amounts of data. The telecommunication transmission speeds have also progressed significantly. Without appropriate image processing hardware, delays would result before a processed image could be available for presentation.

Remote sensing which started with the launching of satellites in the late 1950s has become a very specialized field, having national importance, so that the nations natural resources can be explored, monitored and assessed. Commercial satellite companies are now providing remotely sensed images of sufficiently good resolution to those not in possession of their own satellite.

Camera feature in cellular phones raises the possibility of use by mute persons if practically accurate lip reading capability can be developed in these devices. This would also require a processor powerful enough to handle this level of image processing.

REFERENCES

[1] http://www.hq.nasa.gov/office/pao/History/computers/Ch9-3.html , "Computers in Spaceflight: The NASA Experience"

[2] http://rst.gsfc.nasa.gov/

[3] John E. Zuzek, "The Use of Spaceborne Passive Remote Sensors and Their Radio Spectrum Frequency Needs", Spectrum Management Office, Space Communications Office, NASA, November 1999.

[4] John E. Zuzek, Bryan L. Huneycutt, "Uses of Spaceborne Active Remote Sensors and Their Radio Spectrum Frequency Needs", Spectrum Management Office, Space Communications Office, NASA Jet Propulsion Lab, Spring 1999.

[5] Tomihisa Welsh, Michael Ashikmin, Klaus Mueller, "Transferring color to gray scale images", Center for Visual Computing, Computer Science Department, SUNY at Stony Brook.

[6] Wai-Chi Fang, Michael Jin, "On Board Processor Development For Nasa's Spacebone Imaging Radar With Vlsi System-On-Chip Technology." Jet Propulsion Lab, NASA, ICAS 2004.

[7] Stiefelhagen R., Yang J., Meier U. "Real time lip tracking for lip reading." Proceedings of Eorospeech 1997.

[8] Meier U., Steifelhagen R., Yang J., Waibel A. "Towards unrestricted lip reading." Second International Conference on Multimedia Interfaces, 1999.